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Mediterranean Forests in Transition (MEDIT): Deliverable No5

Title: Report on vegetation dynamics across the Mediterranean basin

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Introduction

In this report we present simulations of two dynamic vegetation models (JULES and TFS) at different study sites across the Mediterranean Basin. The field data and the way that these data have been used to parameterize the two models are described in the accompanying MEDIT Deliverable 4. The aim here is to explore the ability of the models to accurately predict vegetation properties at areas surrounding the Mediterranean basin and in particular the forest types that are the focus of the MEDIT project i.e. Mediterranean Lowland Coniferous Forests (MLC) with typical species including: *Pinus halepensis* and *Pinus brutia*, Mediterranean Evergreen Broadleaved Forests (MEB) with typical species including: *Quercus coccifera, Quercus ilex, Pistacia lentiscus, Phillyrea latifolia, Arbutus unedo* and *Arbutus andrachnae,* Mediterranean Mountainous Coniferous Forests (MMC) with typical species including: *Abies cephalonica, Abies borisii-regis, Pinus nigra* and *Pinus sylvestris*, and Mediterranean Deciduous Broadleaved Forest (MDB) with typical species including: *Quercus frainetto, Quercus cerris, Castanea sativa, Ostrya carpinifolia, Carpinus orientalis, Fraxinus ornus* and *Fagus sylvatica*.

JULES simulations at the local scale, presented in D3.1, did not reasonables estimates of carbon and water fluxes, even when three Mediterranean specific PFTs have been used. Thus a better parameterisation of JULES with the MEDIT dataset does not seem promising. However in this report we present an application of the JULES model at the Mediterranean scale, in order to test whether at larger scales the use of the Mediterranean PFTs would lead to reasonable estimations of Gross Primary Productivity (GPP) and Net Primary Productivity (NPP). To test that we use an independent data source, in particular the "Global Forest Ecosystem Structure and Function Data For Carbon Balance Research" (Luyssaert et al. 2009).

In the previous deliverable (D3.1) developments made to a hybrid DGVM (TFS) have been presented. This model strongly links with the MEDIT dataset and in this document we present a validation exercise for each one of the forest types of interest, and thorough test at one Eddy-Flux Tower data site. In the case of TFS we are interested to accurately simulate carbon and water fluxes at the stand-level as well as some key level properties such as the Leaf Area Index (LAI) at the stand level. If TFS presents a better performance than JULES, then we will further develop it in component 6, in order to achieve Activity 6.2.

JULES Simulations

As described in the previous deliverable the JULES DGVM was reparameterised using data from the MEDIT dataset to better represent Mediterranean PFTs. It was tested against point level data, and showed a rather poor performance. Here we present an evaluation of the reparameterised model for simulations made at the Mediterranean scale. We evaluate its outputs using an second independent data source, of forest structural and functional data (Luyssaert et al. 2009). The variables selected for evaluation are:

- The Gross Primary Productivity (GPP - kgC m^{-2} y^{-1})
- The Net Primary Productivity (NPP - kgC m^{-2} y^{-1})
- The Autotrophic Respiration (Ra - kgC m^{-2} y^{-1})

These variables are related with the equation: $GPP = NPP + Ra$, which suggest an amount of that the gross uptake of CO2 acquired from plants is (GPP) is used for growth and maintenance processes, and the rest is allocated for the production of new biomass (NPP). All these variables have been extracted from the independent validation dataset, in order to be compared with respective estimates from the model.

The JULES model was forced with the 1901-2009 climate. Competition between PFTs was allowed and no predefined vegetation was implemented. Based on the simulated annual evapotranspiration (ET), two ecosystem types were defined, in particular the Mediterranean Warm systems defined here as ET<600mm and Temperate Warm as ET>600mm. This was done in order to have directly comparable results with the independent data source. The Mediterranean warm systems correspond to MEB and MLC types and Temperate Deciduous forest types to our MDB type.

Figure 1 illustrates the simulated GPP across the basin. In this map a higher GPP for more temperate oriented ecosystems is achieved, so the grand scale gradient of ecosystem productivity is as expected. However comparisons against observations at the ecosystem level are not that accurate, with the model underestimating GPP for Mediterranean forests and slightly overestimating GPP for temperate ones.

Figure 2 provides a similar set of simulations and comparisons for NPP. Driven by GPP, NPP is again simulated to be comparatively higher in more temperate oriented biomes. However when compared with observations the model showed a similar to GPP pattern of underestimating Mediterranean and overestimating temperate vegetation.

Simulations of Ra around the basin illustrated a relatively better performance of the reparameterised JULES model (Figure 3). Mediterranean forests were projected to respire less compared to Temperate ones, as also observed in the validation dataset.

Figure 1: JULES simulations of GPP around the Mediterranean basin (left panel). Comparison of simulated vs observed GPP on the right panel

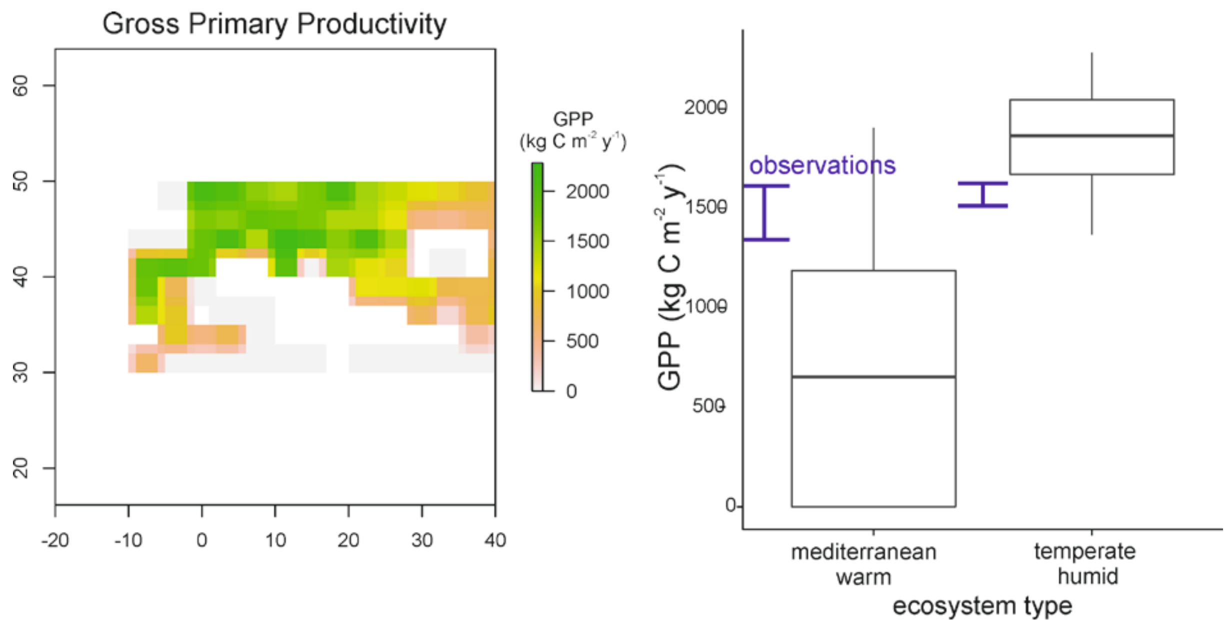


Figure 2: JULES simulations of NPP around the Mediterranean basin (left panel). Comparison of simulated vs observed NPP on the right panel

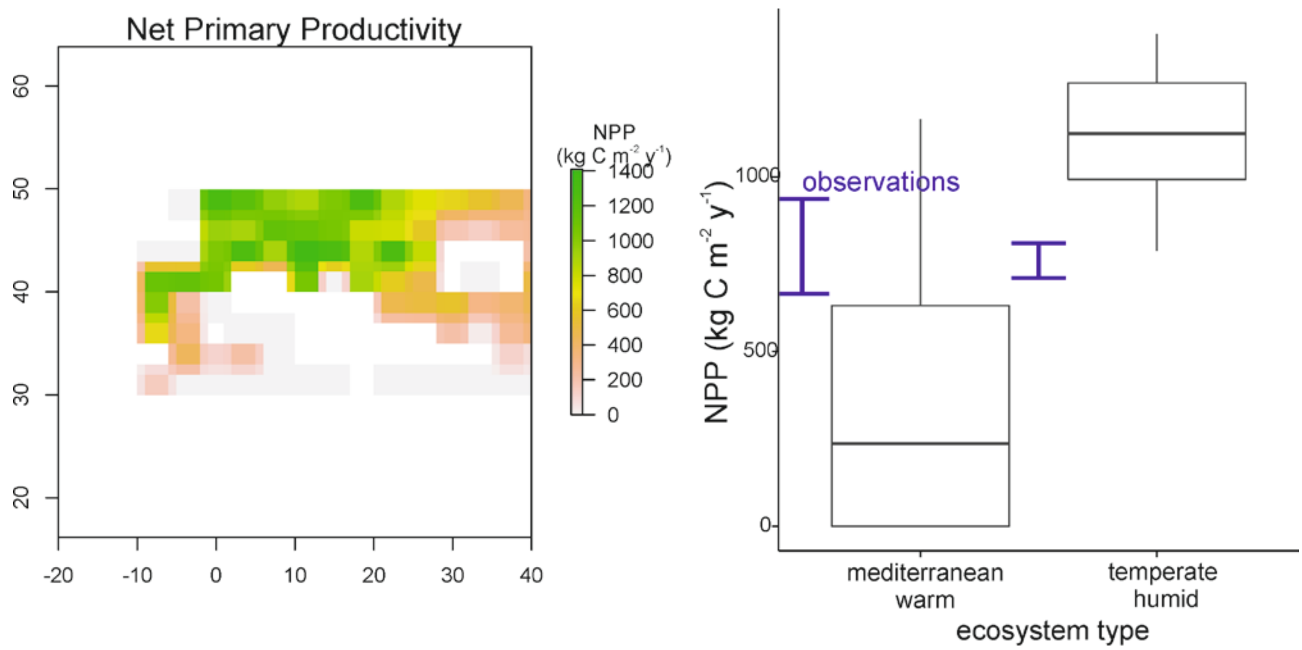
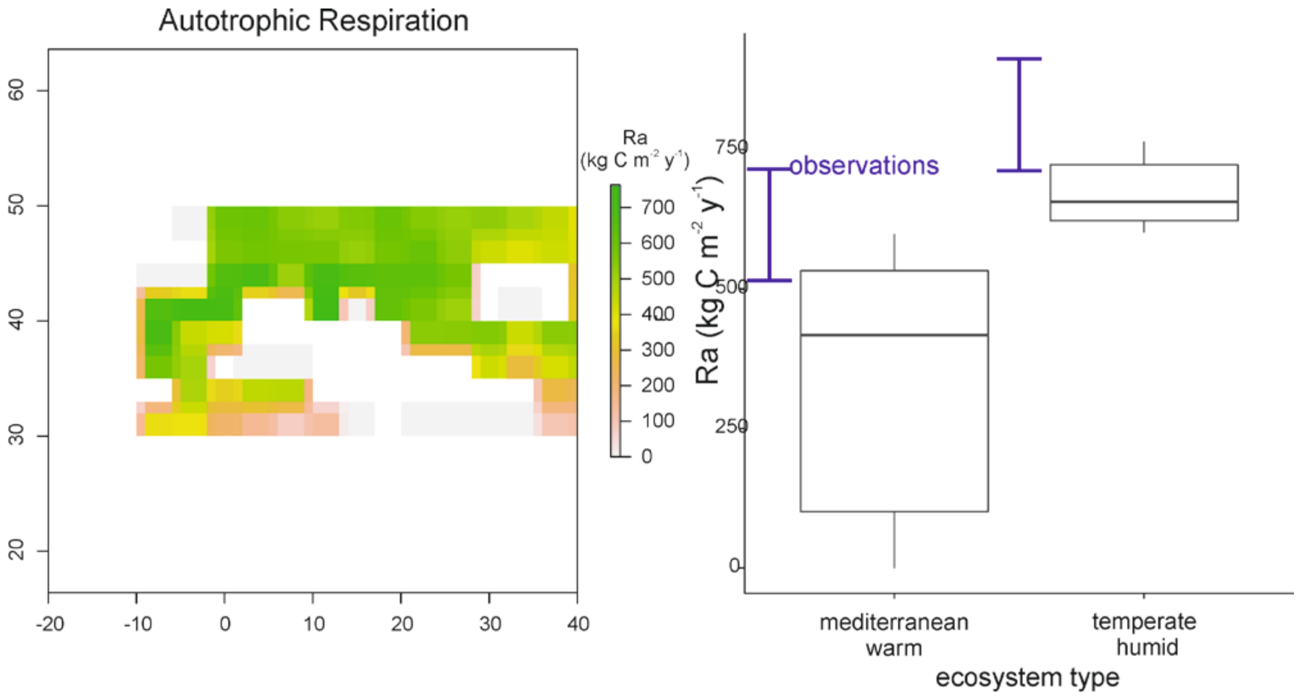


Figure 3: JULES simulations of Ra around the Mediterranean basin (left panel). Comparison of simulated vs observed Ra on the right panel



Conclusions

The inclusion of the three Mediterranean oriented PFTs in the JULES model did not substantially improve its performance. Recent research suggest that variation in ecosystem productivity around the world might be strongly directly related to stand structure and only indirectly to climate (Michaletz et al. 2014). This suggests that representing ecosystem dynamics is a key element of vegetation models. Furthermore the inclusion of trait plasticity instead of static trait values is a "hot" issue in the global ecosystem modelling community (Scheiter and Higgins 2009, Scheiter et al. 2013, Verheijen et al. 2013).

As it will be seen in below, the performance of TFS for various typical Mediterranean forest types is much more accurate even when forced to run without a predefined stand structure. Being a next generation vegetation dynamics model, it also implements the traits continua approach. From the above we decided to further evolve TFS and not JULES, in order to understand Mediterranean forest dynamics and project the potential impacts of climate change impacts on their structure and function. This will be further pursued in component C6.

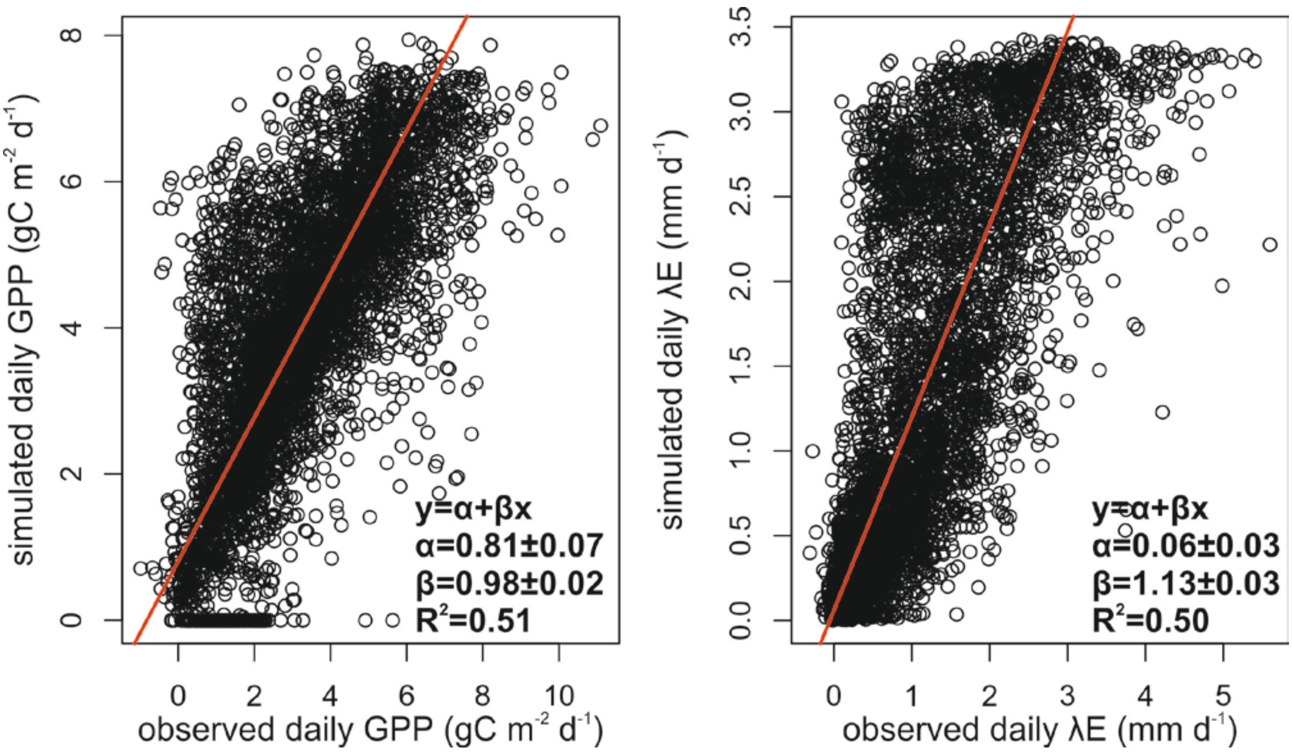
TFS Simulations

Application of TFS at Eddy-Flux Tower Sites, Puechabon.

The new version of the Mediterranean TFS model (developments described in D3.1), was applied under two different setups. The first setup was used to validate the performance of the model against available data from Eddy-Flux sites (Papale and Valentini, 2003). In particular after contacting the Dream CEFE-CNRS team we gained access to one of the longest time-series of Eddy-Flux measurements in Mediterranean ecosystems (Rambal et al., 2004) in Europe (http://fluxnet.ornl.gov/site/487). The Puechabon site is located at Monpellier, France where flux-data have been recorded from 1998 until today. The dominant tree species is *Quercus ilex*, with a canopy height of 6 meters. The leaf area index as measured in 2000 was 2.9. We gained access to data and validated the model for the 2001 to 2013 period.

TFS was forced to run with the daily climate record as recorded from the tower. The variables used to force the model were mean daily temperature, daily precipitation, incoming radiation, atmospheric pressure and specific air humidity. Two variables are used to validate the performance of the model, in particular the latent heat flux (λE in mm) and the gross primary productivity (GPP in gC/m^2) on a daily and on a monthly timestep. Measurements from the MEDIT campaign and in particular for *Quercus ilex* were used to parameterize the variation of the four key functional traits, i.e. leaf dry mass per area (M_A), wood density (WD) and leaf N and P concentrations (N_L, P_L).

Figure 1: Simulated vs observed daily GPP and λE at Puechabon. Simulations with the TFS model were made using the daily climate record for the 2001 t0 2013 period and the *Quercus ilex* trait values from the MEDIT field campaign. A SMA regression was fit with a slope β=0.98 for GPP indicating an accurate model behaviour. A SMA regression was fit with a slope β=1.13 for λE, indicating a slight overestimation.



The model accurately estimated daily GPP for the selected period, as indicated (Fig.1) from the standardised major axis regression with a slope β=0.98, i.e. very close to 1 indicating the perfect model fit to observations. To a lesser degree the same holds true for λE, although in this case the model overestimated the latent heat flux with an estimated slope β=1.13. These outputs suggest that the Mediterranean parameterised version of TFS accurately simulates the daily carbon and water fluxes for the test study site. TFS outputs were also evaluated in terms of accurately representing the seasonal patterns of carbon and water flux. For that reason Fig.2 and Fig.3 are used to compare the monthly patterns of simulated GPP and λE with the observed ones. Apart from the graphical representation, a root mean square error (RMSE) was estimated for each case and for the whole 11 years long period at a monthly time step. A reasonable accuracy of the model was achieved RMSE=38.4 $gm^{-2}mo^{-1}$, within the accepted range of values reported for other vegetation models at Mediterranean ecosystems (Chiesi et al., 2007).

Figure 2: Simulated and observed monthly GPP at Puechabon. Simulations with the TFS model were made using the daily climate record for the 2001 t0 2013 period and the *Quercus ilex* trait values from the MEDIT field campaign. Black lines indicate observations from the Eddy-Flux tower and red lines indicate TFS simulations.

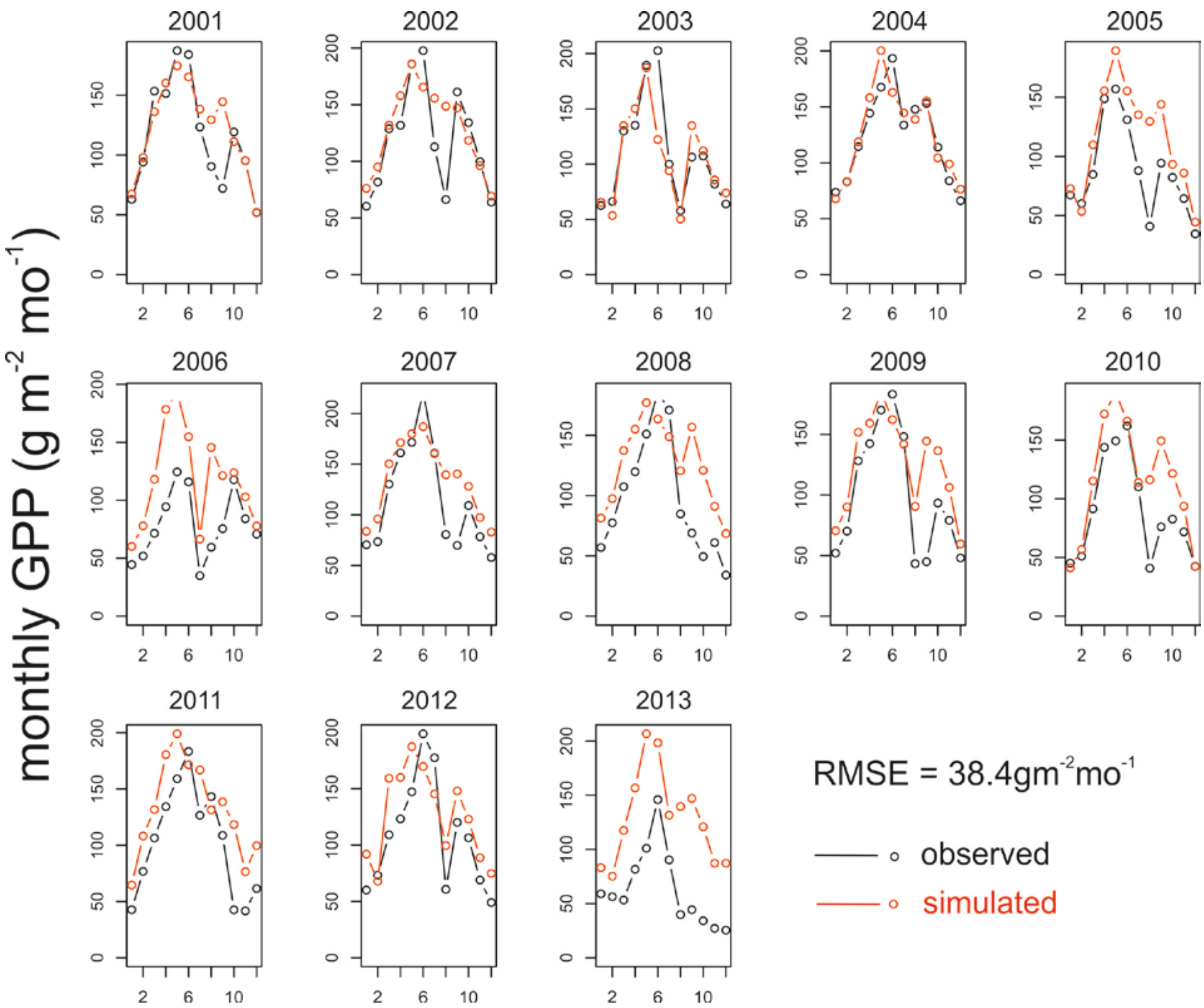
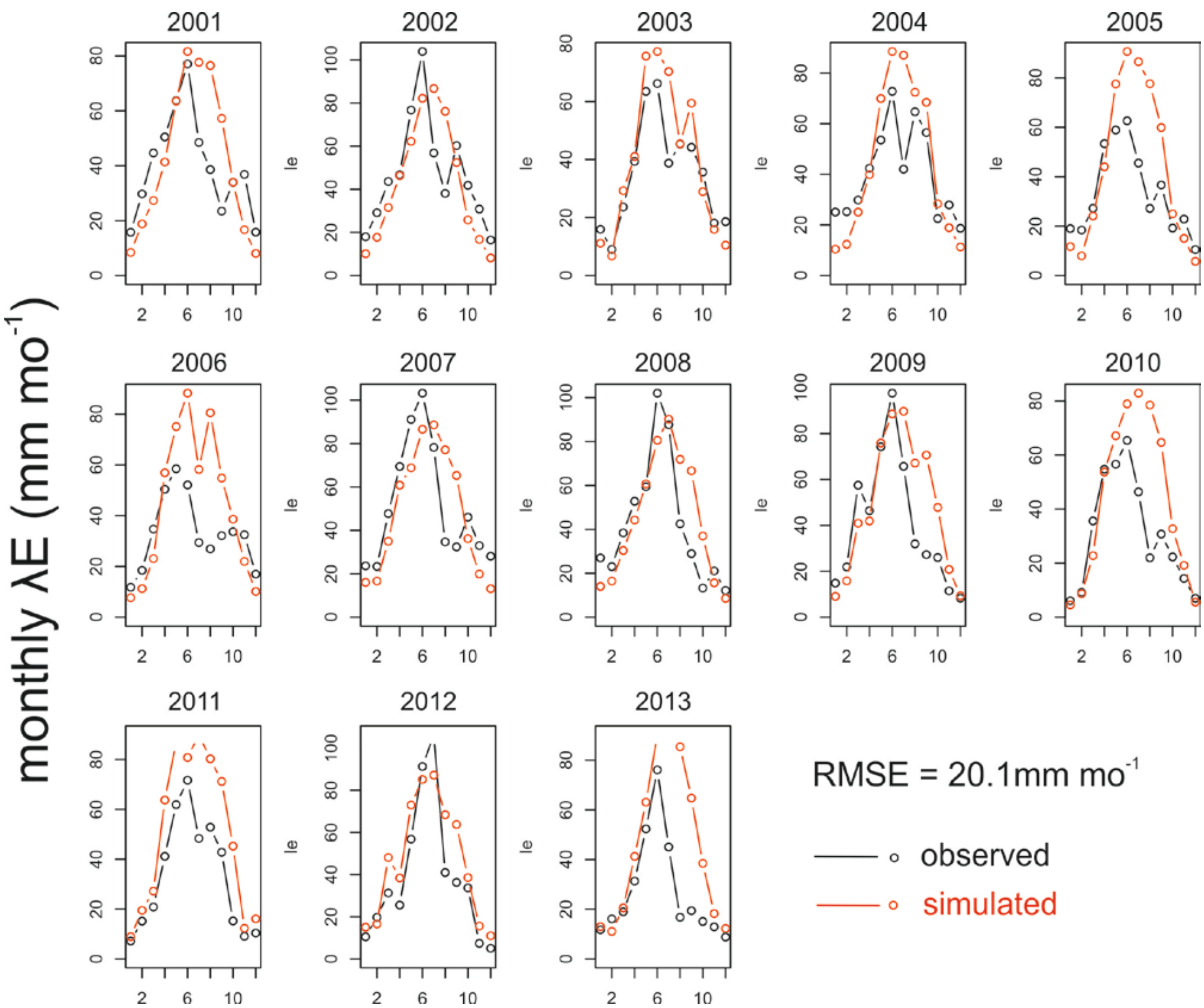


Figure 3: Simulated and observed monthly LE at Puechabon. Simulations with the TFS model were made using the daily climate record for the 2001 t0 2013 period and the *Quercus ilex* trait values from the MEDIT field campaign. Black lines indicate observations from the Eddy-Flux tower and red lines indicate TFS simulations.



Application of TFS at typical Mediterranean and Mountainous Mediterranean sites.

Following the second setup the model was applied at different sites in Greece where data from the MEDIT field campaigns are available. MEDIT monitoring sites that represent the forest types of interest were selected as summarised in Table 1. For each one of these 15 study plots, the site-specific distribution of M_A, WD, N_L and P_L, as well as stand-specific dbh distribution were used to initialize the model. TFS was run for 200 years using the Princeton Climate Database (Shefield et al., 2006). A spin-up period of 100 years was applied and thus the last 100 simulation years were used to estimate the parameters of interest.

Table 1: Characteristics of the Medit Plots used to simulate typical forest ecosystems types found in Greece.

Forest Type	Medit-Code	Region	Dominant Species	Lat	Lon
MLC	PTHA-01	Parnitha	*P. halepensis*	38.2	23.8
MLC	PTHA-03	Parnitha	*P. halepensis*	38.1	23.7
MLC	HYM-01	Hymittos	*P. halepensis*	38.0	23.9
MLC	KIS-05	Kissavos	*P. halepensis*	39.8	22.6
MEB	OLY-08	Olympos	*A. unedo & A. andrachnae*	40.2	22.3
MEB	PSOS-03	Parnassos	*Q. coccifera*	38.6	22.5
MEB	KIS-04	Kissavos	*Q. coccifera*	39.8	22.7
MMC	DOX-01	Helmos	*P. nigra*	37.9	22.3
MMC	DIR-01	Dirfi	*A. cephalonica*	38.6	23.9
MMC	TAY-01	Taygetos	*P. nigra*	37.0	22.3
MMC	VLC-01	Pindos	*A. borisii & P. nigra*	39.9	21.0
MDB	PLA-01	Agrafa	*Q. frainetto*	39.2	21.1
MDB	TAY-03	Taygetos	*Q. frainetto*	37.2	22.2
MDB	KIS-01	Kissavos	*F. sylvatica*	39.8	22.7
MDB	VLC-02	Pindos	*F. sylvatica*	39.9	21.1

The simulated GPP and NPP are compared against the reported GPP from Eddy-Flux Towers across Europe (Jung et al., 2007), the species-specific GPP simulations made by the BIOME-BGC model (Chiesi et al., 2011) and the reported ecosystem type NPP estimates in Chirici et al. (2007). For each ecosystem type we achieved accurate simulations of GPP (Table 2) and improved compared to Chiesi et al. (2011). NPP simulations were accurate in all cases.

Table 2: Comparison of the simulated GPP and NPP for each forest ecosystem type.

Forest Type	GPP (kgC m^{-2} y^{-1}) Jung et al.	GPP (kgC m^{-2} y^{-1}) Chiesi et al.	GPP (kgC m^{-2} y^{-1}) TFS	NPP (kgC m^{-2} y^{-1}) Chirici et al.	NPP (kgC m^{-2} y^{-1}) TFS
MLC	1.59	1.38	1.45±0.27	0.67	0.57±0.21
MEB	1.36	1.24	1.31±0.26	0.75	0.56±0.21
MMC	1.64	1.20	1.75±0.33	0.64	0.77±0.25
MDB	1.12	1.29	1.35±0.36	0.57	0.46±0.18

Conclusions

A new parameterisation of two dynamic vegetation models was achieved. Overall the large scale JULES model seems to perform not as good as the hybrid TFS model. The hybrid TFS accurately predicted water and carbon fluxes for the sites that has been tested. We thus decided to develop a large scale version of TFS. This will be pursued in component C6 in order to simulate Mediterranean forest dynamics under both current and climate change conditions.

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